JSES Reviews, Reports, and Techniques 1 (2021) 414–420

Contents lists available at ScienceDirect

JSES Reviews, Reports, and Techniques

journal homepage: www.jsesreviewsreportstech.org

A biomechanical study comparing the mean load to failure of two different osteosynthesis techniques for step-cut olecranon osteotomy

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A R T I C L E I N F O

Keywords:
Elbow
Trauma
Distal humeral fracture
Olecranon osteotomy
Surgical approach
Biomechanics
Load to failure

Level of evidence: Basic Science Study

Background: Olecranon osteotomies are frequently used to expose distal humeral intraarticular fractures. The step-cut olecranon osteotomy (SCOOT) is an augmented version of the oblique olecranon osteotomy, which has recently been evaluated biomechanically with tension band wiring (TBW) fixation. However, complications with TBW are common. In this study, we, therefore, compared the mean load to failure of TBW with compression screws for SCOOT fixation. We hypothesized a higher load to failure for the compression screw group.

Methods: We performed a SCOOT on 36 Sawbones. Eighteen were fixed with TBW, and another 18 with two compression screws. The humeroulnar joint was simulated using an established test setup, which allows the application of triceps traction force through a tendon model to the ulna, while the humeroulnar joint is in a fixed position. Eight models of each fixation group were tested at 20°, and eight at 70° of flexion by isometrical loading until failure, which was defined as either a complete fracture or gap formation of more than 2 mm at the osteotomy site.

Results: At 20° of flexion, mean load to failure was similar between the TBW group (1360 ± 238 N) and the compression screw group (1401 ± 261 N) (P = .88). Also, at 70° of flexion, the mean load to failure was similar between the TBW group (1398 ± 215 N) and the compression screw group (1614 ± 427 N) (P = .28).

Conclusions: SCOOTs fixed with TBW and compression screws showed similar loads to failure. A SCOOT fixed with compression screws might be a valuable alternative for surgeons when treating intraarticular distal humeral fractures. However, future in vivo studies are necessary to confirm our results in a clinical setting.

Intraarticular distal humeral fractures are relatively rare but challenging to treat. Three approaches are commonly used to expose these fractures: the olecranon osteotomy, triceps splitting approach, and paratricipital approach. According to the literature, olecranon osteotomy provides better exposure of the bony anatomy and is, therefore, considered the gold standard for the most common complex intraarticular fractures.[3,18] Various shapes of osteotomy have been proposed to improve stability and decrease complication rates associated with this approach. Recently, our research group presented the step-cut olecranon osteotomy (SCOOT), which is an augmented version of the extraarticular oblique olecranon osteotomy, with an additional step in the middle third of the osteotomy.[21] The results of this study demonstrated enhanced stability of the SCOOT compared with an oblique olecranon osteotomy and a classic chevron osteotomy.[21] Another anatomic study showed a substantially increased bone contact surface in the area of the SCOOT in comparison with a chevron osteotomy.[22]

Independent of the olecranon osteotomy technique, the following optimal osteosynthesis is controversially discussed. Although the tension band wiring (TBW) osteosynthesis technique has basically been accepted as simple and effective, several studies

This study did not involve human participants, human data, or human tissue, and therefore, ethics approval was waived.

Availability of data and material: The data sets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

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https://doi.org/10.1016/j.xrrt.2021.07.004
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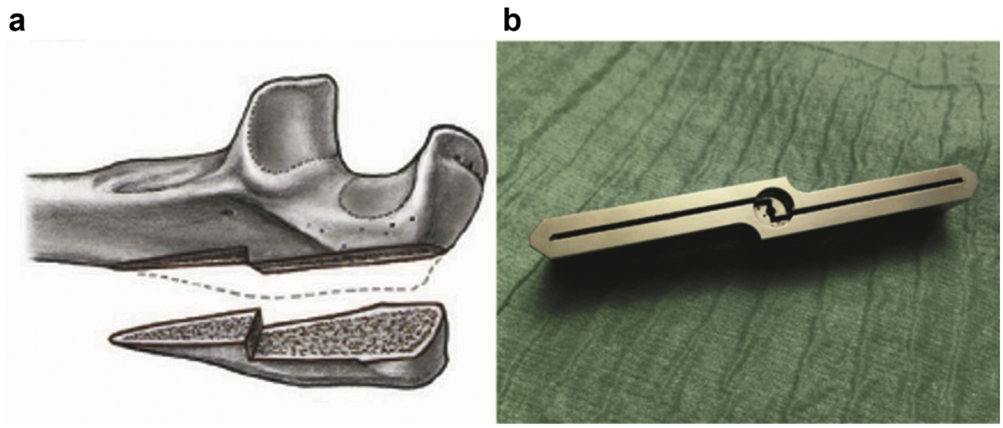

Figure 1 Illustration of (**a**) a step-cut olecranon osteotomy and (**b**) the corresponding cutting guide.

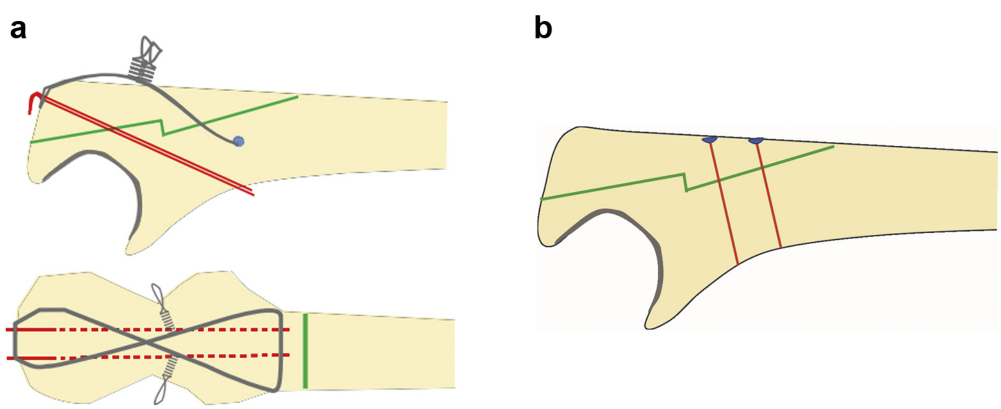

Figure 2 Distal proximal ulna with a step-cut olecranon osteotomy fixed with (**a**) tension band wiring or (**b**) compression screws.

have reported difficulties in the reproducibility[15] as well as high rates of complications, the most common being Kirschner-wire (K-wire) prominence causing skin irritation.[2,4,5,8–10] Furthermore, some studies have questioned the biomechanical principles and advantages of TBW.[7,17,19]

Previously, the stability of SCOOT has only been assessed using the conventional TBW. Therefore, our goal was to compare the load to failure of a SCOOT secured by two compression screws with a SCOOT secured by TBW. Two compression screws were chosen as a potential alternative osteosynthesis technique because the technique might further improve a) the stability of the SCOOT by enhancing force transmission at the step and b) the simplicity of the technique. Based on the aforementioned studies questioning the biomechanical advantages of the TBW, we hypothesized a higher load to failure for the SCOOT fixed with two compression screws.[7,17,19]

Methods

Bone and osteotomy model

We tested 36 fourth-generation composite bones composed of a cortical shell made of short fiber-filled epoxy and a cancellous core made with 17 pounds per cubic foot of solid polyurethane foam (#3426 Sawbones; Pacific Research Laboratories, Inc., Vashon, WA). On each bone model, we performed a SCOOT, an adapted version of the extraarticular oblique olecranon osteotomy as described previously (Fig. 1, *A*) (3). The osteotomy cut was made at the proximal edge of the triceps footprint, 12 mm from the olecranon tip. A specific cutting guide was secured to the bone model with two K-wires to standardize a 2-mm step in the middle third of the osteotomy (Fig. 1, *B*). Two serial, parallel saw cuts were made through the guide, and the osteotomy was completed with a 2-mm osteotome.

Fixation techniques

For SCOOT fixed with TBW, we used a figure-of-eight wire loop as recommended by the Arbeitsgemeinschaft für Osteosynthesefragen (AO Foundation) for olecranon fractures (Fig. 2, *A*).[1] First, we inserted two 1.6-mm K-wires bicortically through the osteotomy and the ulna. They entered dorsally in the proximal ulna between the triceps footprint and the proximal cut of the osteotomy and exited through the anterior cortex at the base of the coronoid process, resulting in a 45° angle to the cutting plane. Second, we drew a line around the ulna at the level of the K-wires' distal cortical exit and drilled a transverse hole through the middle of the ulna. Third, a 1.5-mm stainless steel wire was passed through the hole distally and around the K-wires proximally in a figure-of-eight pattern with two loops for tightening. Finally, the loops were twisted simultaneously until the wire turned white (indicating ideal loading) to reduce and compress the osteotomy.

For SCOOT fixed with compression screws, we first drilled two 2.5-mm bicortical holes (at 10 mm and 30 mm distally from the step osteotomy) from the dorsal ulna perpendicular to the plane of the osteotomy and aiming in anterior-distal direction (Fig. 2, *B*).

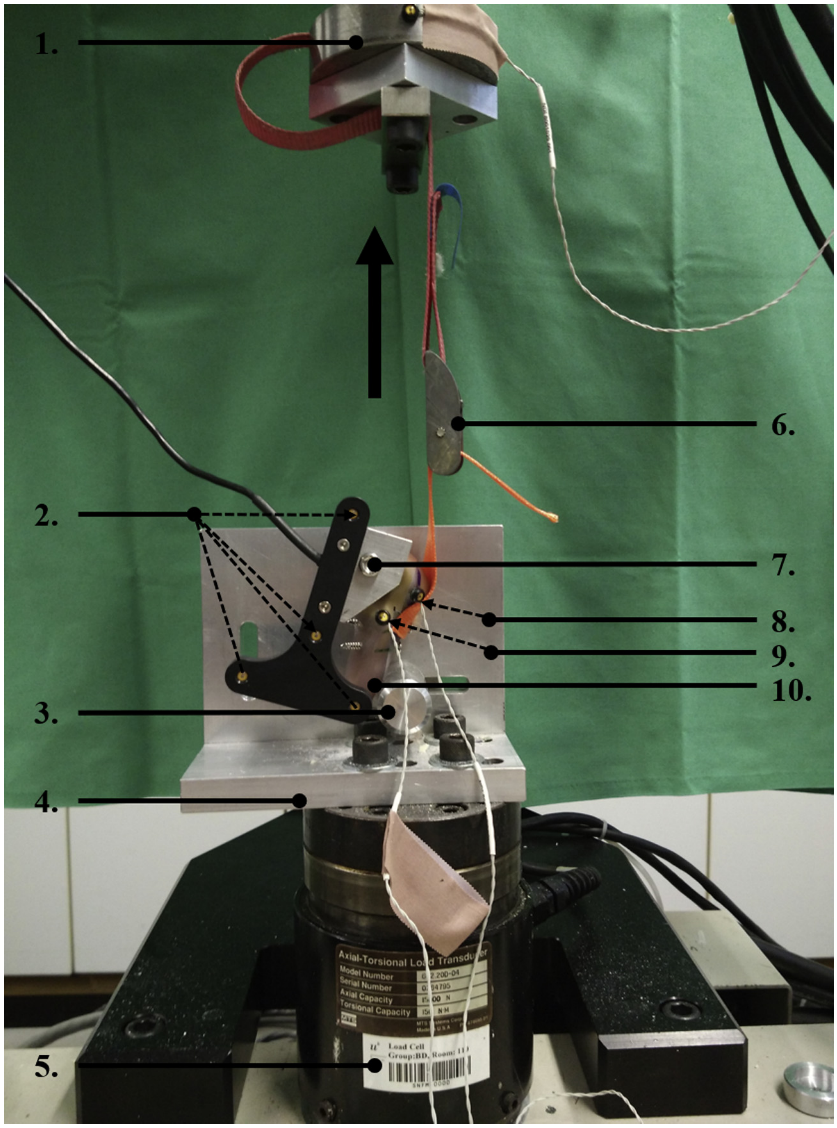

Figure 3 Biomechanical test setup simulating the humeroulnar joint at 70° of flexion fixed with two compression screws. The setup includes (1) a servo hydraulic testing machine, (2) reference markers, (3 and 7) two fixed cylinders, (4) a custom-made aluminum fixation device, (5) a load cell, (6) a synthetic tendon, (8) a dynamic marker, (9) a static marker, and (10) a synthetic ulna bone. The arrow indicates the traction force direction.

Both screw holes were placed distally to the step to prevent intraarticular placement of the screws and increase the safety of the procedure. Each hole was overdrilled to 3.5 mm in the osteotomy segment to generate a lag screw construct. Finally, two 34-mm fully threaded cortical screws were inserted and tightened with two fingers by the same researcher (S.H.).

Biomechanical testing

We applied a validated test setup to simulate a humeroulnar joint (Fig. 3).[12,13,21] For tendon simulation, we used a 25-mm-wide strapping belt with a clamp lock (UK040; ZURRfix AG, Sursee, Switzerland) and attached it on the ulna bone model with an instant adhesive (LOCTITE 401; Henkel AG & Co. KGaA, Dusseldorf, Germany) to mimic the triceps insertion. While the joint was fixed in position by two cylinders, we applied a triceps traction force through the tendon model to the ulna bone model using a servo hydraulic testing machine (MTS Mini Bionix; MTS Eden Hill, PA). The traction force was measured using a load cell mounted onto a custom-made aluminum fixation device.

We tested eight bone models at 20° and eight at 70° of flexion for each fixation technique. As previously described, the position of the elbow joint strongly influences its loading characteristic.[21] We chose these two angles of flexion for the following reasons: At flexion greater than 80°, the tensile forces are absorbed by the entire proximal ulna leading to unphysiologically fractures. At full extension, on the other hand, forces are mainly absorbed by the osteosynthesis material of the osteotomy. Unfortunately, at these angles, the SCOOT also loses its advantage over the oblique osteotomy because the vector of the triceps tensile force does not lead to a bony abutment of the step-cut. Clinically, the highest triceps tensile forces most likely develop during a movement between 20° and 80° of flexion, for example, when getting up from a chair. Hence, beyond the range of 20° to 70° of flexion, no difference between the two groups was expected, and clinically, the highest forces are expected to occur within the range of 20° to 70° of flexion.

Table I
Main test parameters.

	20° Flexion		70° Flexion	
	Tension band wiring	Compression screw	Tension band wiring	Compression screw
Sample size, n	8	8	8	7
Load to failure (N)				
Mean ± SD	1360 ± 239	1401 ± 261	1398 ± 216	1613 ± 427
Median (range)	1385 (1624–894)	1380 (1946–1125)	1368 (1826–1086)	1521 (2273–1092)
Osteotomy fracture, n	0	4	1	3
Fracture of the entire ulna, n	6	4	5	3
Displacement at the osteotomy gap, n	2	0	2	1

N, newton; *SD*, standard deviation.

We tested each humeroulnar test setup by using a constant loading rate of 0.5 mm per second until failure. The endpoints were based on findings from our previous study and described as follows (3):

a) A fracture of the ulna model. We expected no movement for the osteotomies fixed with screws and, thus, a fracture would occur.
b) A shift of the osteotomy along the K-wires, resulting in a gap more than 2 mm between the ulna and osteotomized part, which was previously shown to be connected with post-traumatic osteoarthritis.[11]

We used an optical tracking system (Optotrak 3020; NDI, Waterloo, Canada) with a motion analysis frequency of 25 Hz to measure gap formation and interfragmentary motion at the osteotomy. An infrared light-emitting diode marker with cyanoacrylate was attached on either side of the osteotomy. In addition, four reference markers were attached to the fixation device to define a coordinate system. We used three cameras to capture signals from the reference markers and quantify interfragmentary motion.

Statistical analysis

We performed statistical analysis using R (R Core team, 2017 64-bit version 3.4.1.) and G*Power (64-bit Version 3.1). First, we calculated the sample size needed to find a significant difference in mean load to failure between the groups. The estimated effect size was 1.6 based on the data of our first study (difference between groups 200 N, standard deviation 125 N for both groups).[21] The estimated power and an average effect size of 1.6 was 0.9. Descriptive statistics including means, median, and standard deviations were presented. We used Wilcoxon rank sum tests to compare the fixation groups. The level of statistical significance was set at $P < .05$. P values were adjusted if needed, using the Holm's method to account for multiple comparisons.

Results

The main test parameters are shown in Table I.

At 20° flexion, the mean load to failure in the TBW group (1360 ± 239 N) was not significantly different from the compression screw group (1401 ± 261 N) ($P = .88$) (Fig. 4). In the compression screw group, all bone models failed because of a fracture: The osteotomized part fractured in four bones, and the entire proximal ulna fractured in the other four. In the TBW group, six models failed because of a fracture of the entire proximal ulna. In the other two bone models, a gap emerged between osteotomized part and the ulna.

At 70° flexion, the mean load to failure in the TBW group (1398 ± 215 N) was lower than that in the compression screw group (1614 ± 427 N), but not significantly different ($P = .28$) (Fig. 5). The majority (n = 6) of the bones in the compression screw group failed because of a fracture. However, in one case, the screws were pulled out of the ulna, leading to a gap formation, and in another case, the triceps tendon was torn from the model at a load of 2000 N. As this was not a previously defined endpoint, this sample was excluded from the analysis. In the TBW group, two models failed because of a gap formation, while the other six bone models fractured across the entire proximal ulna.

Discussion

In this biomechanical study, we compared load to failure of a SCOOT secured by two compression screws with that of a SCOOT secured by TBW. The results did not confirm our hypothesis that a higher load to failure for compression screws would be observed. In fact, our study showed similar loads to failure for both fixation techniques.

Numerous studies exist on the loading characteristics of different osteosyntheses techniques for olecranon osteotomies.[7,17,20] A stable osteosynthesis seems best achieved by using either a cancellous screw plus TBW or TBW only. While most studies show slightly higher stability of the cancellous screw with TBW, the exclusive use of TBW seems more common in an everyday clinical setting.[15] Plate fixation offers even more stability, and several clinical trials reported good results.[6,14] However, plate osteosynthesis is more expensive, and hardware removal is frequently required, which must be balanced against the relatively small increase in stability.

Several studies have challenged the widely accepted TBW concept describing the conversion of posterior tensile forces to anterior compressive forces and its use in everyday clinical practice. In a study comparing the stability of different osteosynthesis techniques for transverse olecranon osteotomies using a cadaver model, compression forces were not found posteriorly on the tension side or anteriorly near the articular surface.[7] Similar results were reported for a study evaluating interfragmentary compression in transverse olecranon osteotomies secured with TBW or plate fixation and a study assessing three fixation methods for chevron osteotomy using a roentgen stereophotogrammetric analysis.[17,19] The TBW concept thus remains a point of contention in the literature.

In our previous study, we introduced SCOOT and compared its load to failure with a chevron osteotomy and oblique olecranon osteotomy fixed with TBW and two bicortical K-wires in all cases.[21] Our analysis with the results from our previous study implies a higher load to failure for SCOOT independent of the fixation technique compared to the chevron and oblique olecranon osteotomies fixed with TBW. Using the Wilcoxon rank test, we found the loads to failure at 20° of flexion were significantly higher for the results from this study with both fixation types than those for oblique olecranon and chevron osteotomies fixed with TBW from our previous study ($P < .005$).[21] At 70° of flexion, we found

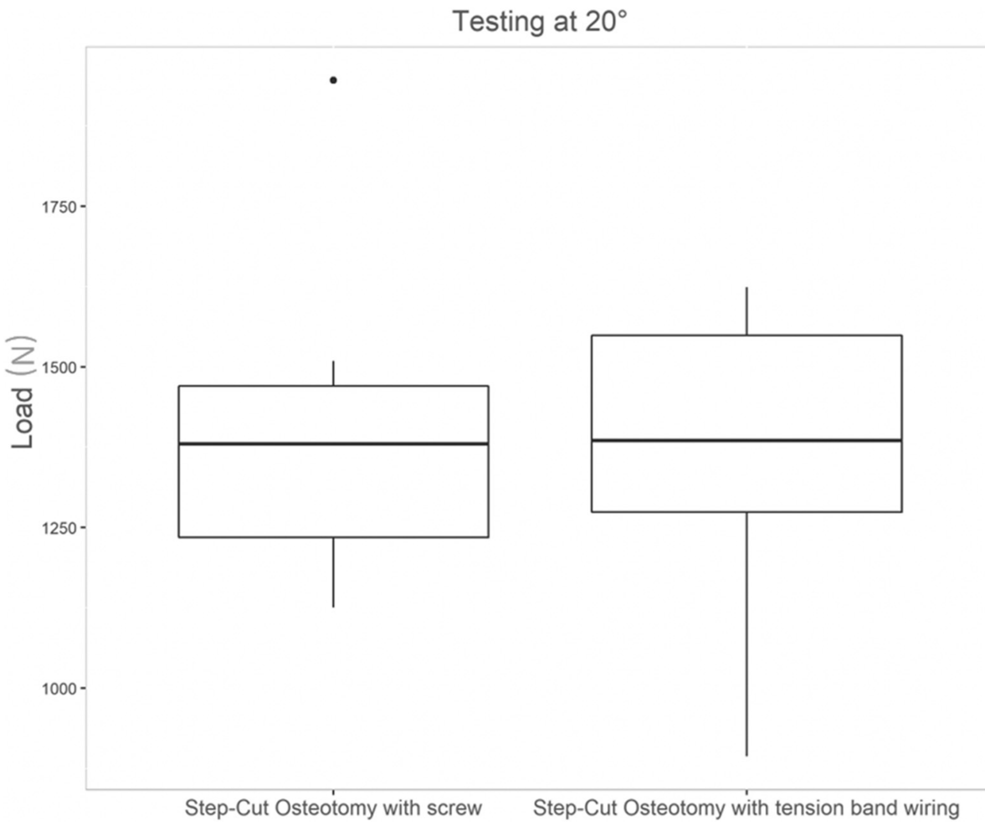

Figure 4 Boxplots showing the load to failure of step-cut olecranon osteotomies fixed with compression screws and tension band wiring at 20° of flexion.

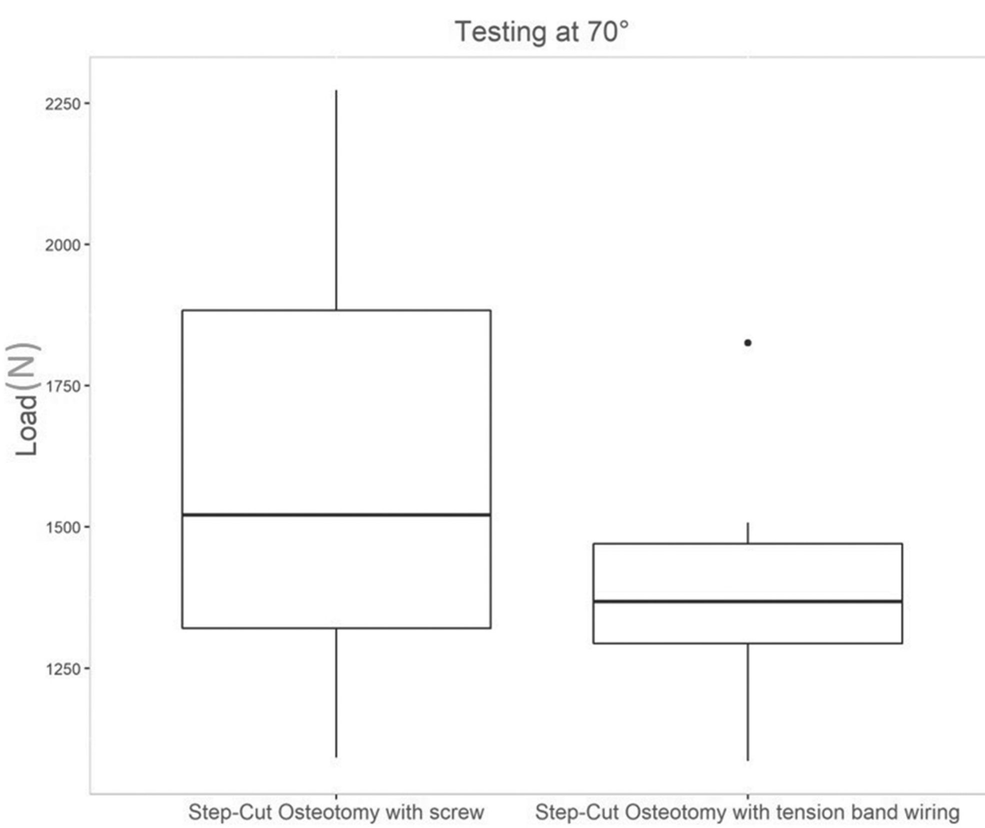

Figure 5 Boxplots showing the load to failure of step-cut olecranon osteotomies fixed with compression screws and tension band wiring at 70° of flexion.

nonsignificant differences between SCOOT fixed with compression screws and oblique olecranon osteotomies fixed with TBW as well for SCOOT fixed with TBW and oblique olecranon osteotomy fixed with TBW ($P = .90$).

Our study has several strengths. First, it is the only study to our knowledge that compared TBW and compression screw for SCOOT fixation biomechanically. It provides a more comprehensive assessment than previous studies on SCOOT, although validation of the results under cyclic loading and at other angles may be useful. Second, from a surgeon's perspective, our results are important and could support the future use of SCOOT with two compression screws. Finally, our study provides valuable information regarding SCOOT. In practice, a SCOOT with screw osteosynthesis should be more resistant to the triceps tension forces than a chevron osteotomy and provide similar stability as an oblique olecranon osteotomy or a SCOOT with TBW. Furthermore, the step of the SCOOT should result in higher rotational stability than the oblique olecranon osteotomy. However, further studies are necessary to investigate the stability of a screw osteosynthesis for the SCOOT in a clinical setting. Nevertheless, it seems safe to assume that the risk of failure is minimal when using a SCOOT fixed with either compression screws or TBW because the mean loads to failure of all groups were much higher than loads usually occurring during early postoperative rehabilitation.[16]

Nevertheless, we acknowledge some limitations. First, our study was performed on a Sawbone model. However, fourth-generation bone surrogates grant constant biomechanical properties, which are remarkably similar to the human bone, and potential differences are expected to be minimal. Second, our test setup only simulated the triceps force. Some authors pointed out the impact of the biceps as well as the brachialis muscle on the humeroulnar joint. However, the impact of these muscles is likely to be limited because they do not attach at the osteotomy site directly. Third, we only simulated isometric muscle contraction and only tested at two angles. Although more extensive testing may be ideal, our method is supported by previous results from our group demonstrating that testing at these two angles is sufficient for biomechanical analysis, and most literature examining olecranon osteotomies and olecranon fractures has tested samples only at one angle (90° of flexion).[21] Fourth, despite load to failure having limited clinical relevance, our study provides evidence that compression screw fixation could be a valuable alternative technique for SCOOT procedures. However, future in vitro and in vivo studies are required to confirm our findings. Finally, the endpoint for most of our test models was an unphysiological fracture. These fractures are most likely caused by a failure of the ulna bone models rather than insufficient osteosynthesis. The formation of a gap in 5 cases in this study is interesting because in our previous study, all 14 SCOOT models failed because of a fracture.[21] However, we observed this endpoint mainly in the TBW group, which could be the result of a suboptimal interaction between the TBW and the SCOOT. Last but not least, some surgeons might be concerned about fractures in the distal portion of the osteotomy due to the 3.5-mm cortical screws. In our study, fractures of osteotomy occurred slightly more frequent in the compression screw group, but they always occurred proximal to the screws in a medial-lateral fashion close to step. Furthermore, based on the biomechanical principles of the construct, most forces should be absorbed by the step rather than the screws. Nevertheless, these concerns are valid, and care should be taken when applying the screws.

Conclusion

Our study demonstrated that loads to failure were similar for TBW and compression screw osteosynthesis for the fixation of SCOOT. Indeed, SCOOT fixed with compression screws might be a valuable alternative for surgeons when treating intraarticular distal humeral fractures. However, our study warrants future in vitro and in vivo studies to confirm these findings.

Disclaimers

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Acknowledgments

The authors would like to thank Hayoz Annabel for her support during the submission process and copyediting of this article and Medical Minds GmbH for providing medical writing and editorial support.

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